

USE OF GLYCURONIC POLYSACCHARIDES AND OLIGOSACCHARIDES
AS PHYTOSANITARY PRODUCTS AND/OR FERTILIZERS

The present invention concerns the use of 1,4 β -D-glucuronan polymers and derived glycuronic oligosaccharides as phytosanitary products and/or fertilizers.

The enzyme 1,3- β -D-glucanase is a marker of defence mechanisms in plants. During reactions caused by hypersensitivity to a pathogen (bacteria, fungi, viruses), the plant reacts by inducing the synthesis of specific proteins named "PR-proteins" (Sintzi A. et al. (1993) Biochimie, 75, 687-706). These proteins, linked with pathogenesis, together with other molecules (such as salicylic acid) contribute to the development of resistance to the pathogen. Depending on their biochemical properties, and their physiological function, these proteins are listed in several groups. They share the following characteristics: low molecular weight, composition most often monomeric, resistance to proteolysis, stability in an acid medium or in extreme temperatures, their association with plasmic or endoplasmic membranes, and their parietal location. Amongst these PR proteins is Group 2, composed of 1,3 β -D-glucanase enzymes, which recognize 1,3 β -D-glucane chains as substrates. The role of these proteins in the defence of the plant is based on their capacity to lyse the walls of pathogens which are rich in 1,3 β -D-glucanes (Boller T. (1993) In Mechanisms of Plant Defenses Responses. Fritig B. Legrand M. eds. Kluwer. Academic Publishers Dordrecht, 391-400).

However, this enzyme activity is not only involved in the defence of plants. In fact it can be regulated by phytohormones and it can be induced at certain stages of development of the plant. On this basis the enzyme 1,3- β -D-glucanase is a marker of growth and/or cell differentiation in plants.

This enzyme, like a number of PR-proteins (protease inhibitors, chitinases, proteins regulating the expression of genes encoding osmotin) are associated with growth and/or cell differentiation or with processes of adaptation to the environment. Some of these proteins are recognized by antibodies directed against 1,3- β -D-glucanases isolated from tobacco contaminated with tobacco mosaic (Kauffmann et al. (1990) Plant Mol. Biol. 14(3): 381-90).

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human or veterinary therapy, cosmetics or water purification, in particular as a gelling, thickening, hydrating, stabilizing, chelating or flocculating agent, as well as in the preparation of oligosaccharides.

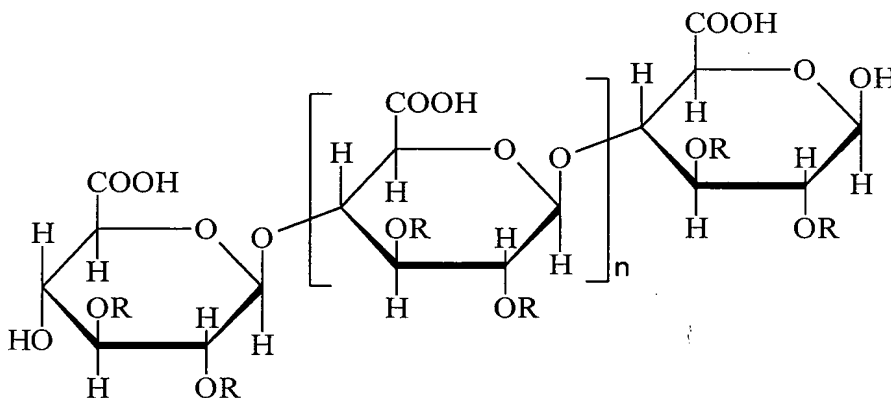
The present invention has the aim of providing compounds which can be used as "elicitors" included in the composition of fertilizers (manure, biological fertilizers or biofertilizers) and phytosanitary products.

One of the aims of the present invention is to provide new biofertilizers which can be used in particular as stimulants of nutrition in addition to or as a replacement for commercial products based on potash and nitrates which are toxic to the environment, and/or as regulators of one or more stages of development of the plants.

Another aim of the present invention is to provide new phytosanitary products which can be used in particular as activators of defence and resistance reactions against biotic or abiotic stresses in addition to or as a replacement for pesticides which are toxic to the environment.

The present invention has as its subject the use of compounds chosen from:

- 1,4 β -D-glucuronan polymers of formula (I) below:



in which n is an integer which may be as great as approximately 2500, advantageously n is between approximately 300 and approximately 2500, and R represents H or $COCH_3$.

- and/or the $\beta(1-4)$ chain glycuronic oligosaccharides derived from polymers of formula (I), and of which the number of saccharidic units is less than approximately 30, and preferably between 2 and 15,

– and/or the esters and/or ethers corresponding to polymers of formula (I) or to the above mentioned oligosaccharidic derivatives,

- * as phytosanitary products within the framework of uses linked to their activity of amplifying the enzyme 1,3 β -D-glucanase,
- * and/or as biofertilizers within the framework of uses linked to their activity of amplifying the enzyme 1,3 β -D-glucanase, and/or the enzyme 1,4 β -D-glucanase, and/or xyloglucan endotransglycolase.

Of the plants which can be treated within the framework of the present invention, the following may be cited: vines, fruit trees, cereals and market garden produce, or any other plant of economic interest.

The invention has more particularly as its subject the above mentioned use of compounds chosen from those cited above, as phytosanitary products within the framework of uses linked to their activity of amplifying the enzyme 1,3 β -D-glucanase, such as the protection of plants against pathogens or predators, notably against bacteria, viruses, fungi, insects, nematodes, or the adaptation of plants to an abiotic stress, in particular adaptation to cold, or to raised ozone levels.

The invention has more particularly as its subject the use, as phytosanitary products, of 1,4 β -D-glucuronan polymers of formula (I) in which n is an integer between approximately 300 and approximately 2500, and R represents H.

The invention also has more particularly as its subject the use, as phytosanitary products, of 1,4 β -D-glucuronan polymers of formula (I) in which n is an integer between approximately 300 and approximately 2500, R represents H or COCH₃, the weight percentage of COCH₃ preferably being between 0 and 30.5.

The invention also concerns the use, as phytosanitary products, of β (1-4) chain glycuronic oligosaccharides, such as the oligo 1,4 β -D-glucuronans, the oligo 1,4 β -D-mannuronans, and the oligo 1,4 β -D-guluronans, whose DP (degree of polymerization) is less than 30, and preferably between 2 and 15.

In the following, the expression "oligosaccharides with a degree of polymerization x (DPx)" shall be understood as meaning oligosaccharides made up of the same number x of saccharidic units, and the expression "oligosaccharides with an average degree of polymerization x (average DP x)" shall be understood as meaning oligosaccharides made up of a variable number of saccharidic units, whose average corresponds to x.

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Glycuronic oligosaccharide derivatives preferred as phytosanitary products are chosen from the following:

- the oligo 1,4 β -D-glucuronans of DP8, and of average DP 8
- the oligo 1,4 β -D-mannuronan of DP4,
- the oligo 1,4 β -D-guluronan of DP4.

The invention also has as its subject a process for the treatment of plants with 1,4 β -D-glucuronan polymers and/or glycuronic oligosaccharides as defined above, with a view to obtaining plants resistant to the above mentioned pathogens, or adapted to an abiotic stress, notably the cold, or raised ozone levels.

The invention also concerns the use of compounds chosen from those cited above, as biofertilizers within the framework of uses linked to their activity of amplifying the enzyme 1,3 β -D-glucanase, and/or the enzyme 1,4 β -D-glucanase and/or the enzyme xyloglucan endotransglycolase.

The invention has more particularly as its subject the above mentioned use of oligo 1,4 β -D-glucuronans, whose DP is below 30, and preferably between 2 and 15, as biofertilizers within the framework of uses linked to their activity of amplifying the enzyme 1,3 β -D-glucanase, and/or the enzyme 1,4 β -D-glucanase, notably within the framework of control of one or more stages of plant development, such as the control of fruit maturation, abscission, growth of the pistil or maturation of the anthers.

The invention has still more particularly as its subject the above mentioned use of oligo 1,4 β -D-glucuronans of DP8 and average DP 8, as biofertilizers.

The invention has more particularly as its subject the above mentioned use of oligo 1,4 β -D-mannuronans, whose DP is below 30, and preferably between 2 and 15, as biofertilizers within the framework of uses linked to their activity of amplifying the enzyme xyloglucan endotransglycolase, notably within the framework of control of the organization of cell walls during expansion of the tissues (vascular zones or parenchyma) of certain organs such as hypocotyls, cotyledons, leaves, pollen tubes, and fruits, and to reinforce the plant cell walls and adapt them to environmental stimuli such as wind, thermal or water shock, or mechanical pressure.

The invention also has as its subject a process for the treatment of plants with glycuronic oligosaccharides as defined above, with a view to obtaining plants in which one or more stages of development, such as fruit maturation, abscission, growth of the pistil or maturation of the anthers, are controlled over time.

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The invention also has as its subject a process for treatment of plants with glycuronic oligosaccharides as defined above, with a view to obtaining plants, in which the organization of cell walls during expansion of the tissues is controlled, and in which the plant cell walls are reinforced to adapt them to environmental stimuli such as wind, thermal or water shock, or mechanical pressure.

The invention also concerns phytosanitary products and/or biofertilizers characterized in that they include at least one compound chosen from:

- 1,4 β -D-glucuronan polymers of formula (I) mentioned above, in which n is an integer between approximately 300 and approximately 2500, and R represents H or COCH₃,

- and/or β (1-4) chain glycuronic oligosaccharides derived from polymers of formula (I), and of which the number of saccharidic units is less than approximately 30,

- and/or the esters and/or ethers corresponding to polymers of formula (I) or to the above mentioned oligosaccharidic derivatives.

The invention has more particularly as its subject phytosanitary products comprising at least one 1,4 β -D-glucuronan polymer of formula (I) in which n is an integer between approximately 300 and approximately 2500, and R represents H.

The invention also concerns phytosanitary products comprising at least one 1,4 β -D-glucuronan polymer of formula (I) in which n is an integer between approximately 300 and approximately 2500, R represents H or COCH₃, the percentage of COCH₃ by weight being preferably between 0 and 30.5.

The invention also has as its subject phytosanitary products, comprising at least one β (1-4) chain glycuronic oligosaccharide, such as the oligo 1,4 β -D-glucuronans, the oligo 1,4 β -D-mannuronans, and the oligo 1,4 β -D-guluronans, whose DP is less than 30, and preferably between 2 and 15.

The invention has more particularly as its subject, phytosanitary products comprising at least one glycuronic oligosaccharide derivative chosen from the following:

- the oligo 1,4 β -D-glucuronans of DP8, and of average DP 8
- the oligo 1,4 β -D-mannuronan of DP4,
- the oligo 1,4 β -D-guluronan of DP4.

The invention concerns more particularly biofertilizers comprising at least one oligo 1,4 β -D-glucuronan whose DP is below approximately 30, and preferably between

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2 and 15, and, preferably, biofertilizers comprising oligo 1,4 β -D-glucuronans of DP8, and of average DP 8.

The invention concerns still more particularly biofertilizers comprising at least one oligo 1,4 β -D-mannuronan whose DP is below approximately 30, and preferably between 2 and 15, and, preferably, biofertilizers comprising the oligo 1,4 β -D-mannuronan of DP4.

The invention will be further described by means of the following detailed description of the preparation of 1,4 β -D-glucuronan polymers and glycuronic oligosaccharides derived according to the invention, as well as the demonstration of their properties of amplifying the enzyme 1,3 β -D-glucanase and/or the enzyme 1,4 β -D-glucanase.

A) Preparation of uronic polymers and/or their oligosaccharides

1,4 β -D-glucuronan polymers are obtained using fermentation processes of strains of bacteria isolated from the rhizosphere (*Rhizobium*, *Sinorhizobium*, *Agrobacterium*, *Pseudomonas*, *Burkholderia* etc.) which may or may not be modified by chemical mutations and/or genetic manipulations.

1,4 β -D-glucuronan polymers can thus be obtained by selective oxidation of cellulose according to the processes described in various articles (Painter T.J., 1977, Preparation and periodate oxidation of C-6-oxycellulose: conformational interpretation of hamlacetal stability. Carbohy. Res. 55, 95-103; Chang P.S. and Robyt J.F., Oxidation of primary alcohol groups of naturally occurring polysaccharides with 2, 2, 6, 6-tetramethyl-1-piperidine oxoammonium ion. J. Carbohydr. Chem., 15, 819-830; Isogai, A. and Kato, Y., 1998, Preparation of polyuronic acid from cellulose by TEMPO-mediated oxidation, Cellulose, 5, 153-164).

If necessary, the polymers thus obtained are modified and/or degraded by chemical and/or enzymatic means, during fermentation or by post-fermentation treatments.

- 1,4 β -D-glucuronan polymer

By way of illustration, 1,4 β -D-glucuronan polymer is obtained by fermentation of a mutated strain of *Rhizobium meliloti*, according to the protocol described in the French patent FR-B-2 688 222 of 3 March 1992.

- 1,4 β -D-glucuronan oligomer of average DP 8

The previous native polymer, i.e. comprising at least 50% acetylated glucuronic units at C2 and at C3, is subjected to enzymatic hydrolysis. The enzyme is a glucuronate lyase of various origins, notably extracted from the pancreas of ormers, or of fungal origin (Dantas L. et al., Carbohydr. Res., 265 (1994) 303-310) or a glucuronate lyase present in the culture medium of bacteria such as strains of Rhizobiaceae (Michaud P., et al., Int. J. Biol. Macromol. 21 (1997) 3-9). The mixture of oligosaccharides thus obtained is deacetylated by a basic process (NaOH 0.1M), then fractionated on the basis of the degree of polymerization (DP) by gel-permeation chromatography using a BioGel P6 column (Dantas L. et al., mentioned above).

- 1,4 β -D-mannuronan and 1,4 β -D-guluronan oligomers of DP 4.

The starting polymer is an alginate, linear copolymer of mannuronic (M) and guluronic (G) acids, whose M/G ratio and mode of arrangement depend on the origin. The alginate is chosen on the basis of the type of oligomers to be prepared. Hydrolysis is carried out by enzymatic means: an alginate-lyase of ormer origin for the oligo-1,4 β -D-mannuronans (Heyraud A. et al., Carbohydr. Res., 291 (1996) 115-126), an alginate-lyase of bacterial origin for the oligo-1,4 β -D-guluronans (Patent FR 97 03218 of 11 March 1997). The different oligosaccharides, separated according to DP by gel-permeation chromatography, are then purified depending on their structure by ionic chromatography in high-pressure liquid chromatography according to the process described in the article by Heyraud et al., mentioned above.

B) 1,3 β -D-glucanase response induced in the protoplasts of *Rubus*.

Experimental conditions: (1) preparation of protoplasts from cell suspensions of *Rubus fruticosus* L.; (2) incubation, or not, of n samples of $2 \cdot 10^6$ protoplasts in the presence of "elicitors" (1,4 β -D-glucuronan polymers and 1,4 β -D-galacturonan (400 μ g/L) polymers, 1,4 β -D-glucuronan oligomers of average DP 8, 1,4 β -D-mannuronan oligomers of DP 4, and 1,4 β -D-guluronan oligomers of DP 4 (50 nM)); (3) after 20

minutes, the protoplasts whether may be treated or not, are subjected to enzymatic extraction. 2 μg of proteins are used per enzymatic test, and per incubation period. The viability of the protoplasts is maintained at 95% for an experimental period of 6 hours; the Evans blue viability test used verifies the integrity of the plasmalemma.

Methodology: measurement of activity (1,3 β -D-glucanase) is based on the colorimetric dosage (ferricyan test) of the substrate-reducing units (reduced hexamer from laminarin) released during hydrolysis. Based on the kinetics developed, curves are traced whose equations make it possible to calculate the speed of the enzymatic reaction. 2 kinetics, at least, are developed per sample, and per experimental "set". In general, at least 8 kinematics from samples of 2 independent "sets" are developed.

Results: the enzymatic activation elicited in the protoplasts is expressed as a % of the activity in the controls. The results are summarized in Table 1.

Table 1

"elicitor"	activity (% control)
a	145
b	128
c	100
d	122
e	146

Table 1: Comparative analysis of the responses (1,3- β -D-glucanase) induced by the "elicitor" (1,4 β -D-glucuronan polymer (400 $\mu\text{g/L}$) (a), oligo 1,4- β -D-glucuronan of average DP 8 (50 nM) (b), 1,4- β -D-galacturonan (400 $\mu\text{g/L}$) (c), oligo 1,4- β -D-mannuronan of DP 4 (50 nM) (d), oligo 1,4- β -D-guluronan of DP 4 (50 nM) (e).

Electrophoretic analysis by SDS-PAGE of the proteins making up the enzymatic extracts has been carried out. The marking of proteins on prints by a serum recognizing 1,3- β -D-glucanases isolated from tobacco contaminated with tobacco mosaic (Ori et al. (1990) EMBO J., 9(11), 3429-36) confirms the presence of PR proteins.

The 1,4- β -D-glucuronan oligomer of average DP 8 and the polyglucuronan, used at a nanomolar concentration, in 20 minutes amplify by a factor of 1.5 and 1.3

respectively the 1,3- β -D-glucanase activity in plant protoplasts. Amongst the other products tested, oligo 1,4- β -D-guluronan of DP4 was the most effective.

C) 1,4 β -D-glucanase response induced in protoplasts of *Rubus*

Experimental elicitation conditions: identical to those reported above.

Methodology: measurement of activity (1,4 β -D-glucanase) is based on the colorimetric dosage (ferricyan test) described above of the substrate-reducing units (reduced cellopentaose) released during hydrolysis.

Results: The results are shown in Table 2.

Table 2

"elicitor"	activity (% control)
a	100
b	120
c	100
d	-
e	101

Table 2: Comparative analysis of the responses (1,4 β -D-glucanase) induced by the "elicitor" (1,4 β -D-glucuronan polymer (400 μ g/L) (a), oligo 1,4 β -D-glucuronan of average DP 8 (50 nM) (b), 1,4 β -D-galacturonan polymer (400 μ g/L) (c), oligo 1,4 β -D-mannuronan of DP 4 (50 nM) (d), oligo 1,4 β -D-guluronan of DP 4 (50 nM) (e).

The 1,4- β -D-glucuronan oligomer of average DP 8 used at a nanomolar concentration, in 20 minutes amplifies by a factor of 1.2 the 1,4 β -D-glucanase activity in plant protoplasts.

D) Xyloglucan endotransglycolase response induced in protoplasts of *Rubus*

Experimental elicitation conditions. $2 \cdot 10^6$ protoplasts in 1 ml Tris-HCl buffer (pH 4.8) are incubated in the presence, or not, of an elicitor (50 nM) or of a hormone (50nM): mannuronan oligomer of DP4 or glucuronan oligomer of DP8 or gibberellin

GA3. After 20, 40, 60, 100 and 120 minutes of interaction, the protoplasts are recovered by centrifugation, then subjected to enzymatic extraction.

Methodology: measurement of XET activity is carried out in the wells of microtitration plates in 4 stages. Stage 1: immobilization of the acceptor, i.e. the neoglycoprotein XXLG \approx BSA. Stage 2: introduction of the reaction medium (XET enzymatic extraction (equivalent to 1 μ g of proteins) substrate marked DIG, i.e. XG \approx DIG in the Tris-HCl buffer, pH = 7, 25 mM). Stage 3: immunomarking according to the anti-DIG marked peroxidase sequence, anti-peroxidase marked peroxidase. Stage 4: dosage of the peroxidase activity in a citrate-phosphate buffer (50nM, pH 5.5).

The peroxidase activity is measured at 492 nm. At least 3 curves of peroxidase activity are traced per experimental condition, and the experiments are carried out using 3 protoplast suspensions. The XET activity is measured by the slope (ΔA 492) of the curve deduced by linear regression from 9 peroxidase kinetics curves.

Abbreviations:

DIG: digoxigenin

XET: xyloglucan endotransglycolase - XG: xyloglucan polymer - XXLG: non-fucosylated xyloglucan oligomer.

Results: The results are indicated in Figure 1.

The mannuronan oligomer of DP4 (MAN) induces the strongest XET response (amplification in 20 minutes by a factor of 2.12); the glucuronan oligomer of DP8 (GLUC) and the hormone (GA3) are less effective (amplification in 20 minutes by a factor of 1.62 and 1.12 respectively). The reference XET activity is that of the non-elicited protoplasts (CONTROL).

Legend to figure 1: XET activity is indicated on the Y-axis, and time on the X-axis; the curve following the triangles corresponds to the results obtained with the mannuronan oligomer of DP4 (MAN), the curve following the crosses corresponds to the results obtained with the glucuronan oligomer of DP8 (GLUC), the curve following the circles corresponds to the results obtained with the hormone (GA3), the curve following the squares corresponds to the results obtained with the control.